HAL open science

Development of Diamond Sensors for Beam Halo and Compton Spectrum Diagnostics after the Interaction Point of ATF2

S. Liu, P. Bambade, S. Bai, T. Tauchi, N. Terunuma

To cite this version:

S. Liu, P. Bambade, S. Bai, T. Tauchi, N. Terunuma. Development of Diamond Sensors for Beam Halo and Compton Spectrum Diagnostics after the Interaction Point of ATF2. IPAC 13 - 4th International Particle Accelerator Conference, May 2013, Shanghai, China. pp.470-472. in2p3-00822890

HAL Id: in2p3-00822890
https://hal.in2p3.fr/in2p3-00822890

Submitted on 29 Jul 2013

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

DEVELOPMENT OF DIAMOND SENSORS FOR BEAM HALO AND COMPTON SPECTRUM DIAGNOSTICS AFTER THE INTERACTION POINT OF ATF2*

Shan Liu, Philip Bambade, LAL, Orsay, France

Sha Bai, IHEP, Beijing, China

Toshiaki Tauchi, Nobuhiro Terunuma, KEK, Tsukuba, Japan

Abstract

ATF2 is a low energy (1.3GeV) prototype of the final focus system for ILC and CLIC linear collider projects. A major issue at ATF2 and in linear colliders is to control the beam halo, which consists of tails extending far beyond the Gaussian core of the beam. At present there is no dedicated collimation for the beam halo at ATF2, and the transverse distribution near the interaction point is not well known. The development of a sensor based on CVD diamond to scan the beam halo in the vacuum chamber a few meters after the interaction point is presented. This system also aims to detect the Compton recoil electrons generated by the laser interferometer (Shintake monitor) used to measure the beam size at the interaction point of ATF2.

INTRODUCTION

A major issue in ATF2 [1] and in linear colliders, as well as in many other accelerator facilities for high energy physics, is controlling the beam halo before the collision point. Beam halo consists of tails extending far beyond the Gaussian core of the beam. Although halo can be generated in many processes including beam-gas and thermal photon scattering, transverse wakefields, nonlinear fields in the magnets etc., the main source of beam halo at ATF2 is expected from intra-beam scattering in the ATF damping ring [2]. The amount of beam halo, as shown in some early measurements at ATF2, is typically ~10^{-3} of the total beam. When these tail particles reach the vacuum chamber and start showering in the material, large numbers of secondary particles are produced. Tail particles are most likely to be intercepted in the beam pipe in last focusing quadrupoles, just before the collision point, and in the post-IP beam line. In a linear collider, such particle losses would be unacceptable, as the produced secondary particles would have devastating effects on the experiments.

At the focal point of ATF2, a Shintake monitor is used for the nano meter beam size measurement. This monitor is based on setting up an interference pattern between two laser beams and detecting the Compton scattered γ photon rate while the beam is scanned across the interference fringes [3]. This tool is very sensitive to bremstrahlung photons emitted when halo particles are intercepted are intercepted by the beam pipe near the collision point. Although specific collimation has been installed to shield the solid angle of the γ photon detector against such bremstrahlung photons, this background remains a major source, when using the nominal demagnification of the optics.

An alternative technique to measure the rate of Compton scatters during the interaction of the beam with the interference fringes is to detect the recoil electrons. Since these electrons have up to 2.23% lower energy as compared to other beam particles, detection behind a large 20° bending magnet used after the collision point can be considered. The visibility in the presence of the beam halo has been checked in simulation and the beam halo collimation has been studied in detail. For the detection of both beam halo and Compton electrons, a single layer of diamond detector with some spatial segmentation covering a few tens of mm^2 can be positioned in the vacuum chamber, near the beam, using a movable stage.

BEAM HALO COLLIMATION AND MEASUREMENT

The first beam halo measurements were done in 2005 using the wire scanners located in the upstream part of ATF2 [3]. These measurements provided us with the first information about beam halo distribution in the extraction line, allowing us to prepare several simulations of the halo generation and transport along the ATF2 beam line, using both MAD-X and GEANT4. As the energy spread of beam halo is not well known, we used two different extreme energy spread models: 1) $\delta p/p_0=0.0008$ with Gaussian distribution; 2) $\delta p/p_0=0.01$ with flat distribution. We have estimated the charge signal that would be generated in a 500 μm thick single crystal CVD diamond sensor from the beam core, the beam halo and the Compton recoil electrons (see Table 1).

*Work supported by the CSC (File NO.201206170138).
sliu@lal.in2p3.fr

Copyright © 2013 by JACoW — cc Creative Commons Attribution 3.0 (CC-BY-3.0)

Table 1: Estimation of Charge Signal in 500μm Thick Single Crystal CVD Diamond

	Total Number	Max. Number/mm^2	Charge Signal/mm^2
Beam Core	10^{10}	6.16×10^{8}	1.6887μC
Halo ($\delta p/p_0$=0.0008)	10^{7}	2.24×10^{4}	61.376pC
Halo ($\delta p/p_0$=0.01)	10^{7}	1.14×10^{4}	31.236pC
Compton Electron	2834	30～520	82.2fC～1.4284pC

Comparing with the beam halo signal, the Compton electrons have such a small signal that it might be covered by the signal of horizontal halo with large energy spread if no dedicated collimation will be applied. Besides, the collimation for vertical beam halo is also very important, as it might hit the beam pipe in the BDUMP bending magnet and generate second generation particles. Thus, we have studied both the horizontal and vertical halo collimation.

Horizontal Halo Collimation

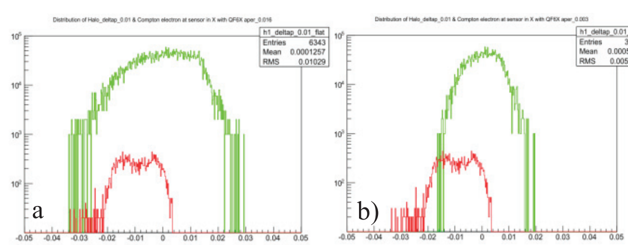

Figure 1: Distribution of halo (green) and Compton (red) in the horizontal plane at the diamond detector location for a) initial QF6 aperture with a radius of 0.016m and for b) a smaller aperture of 0.003m. The energy spread used for these simulations is 0.01 with a flat distribution.

The horizontal halo can cover the Compton signal if the energy spread of halo is very big. Figure 1a shows the simulation results for the distributions of beam halo and Compton electrons in horizontal plane at the location where we intend to put the diamond detector. For the purpose of detecting Compton electrons, it is necessary to add energy collimator to collimate the horizontal halo with large energy spread. The location to put such collimators can be found by searching for the location with maximum ratio between the energy dependent deviation and the nominal beam size, i.e. the maximum value for $D_x/\sqrt{\beta_x}$. In the ATF2 line the maximum value for $D_x/\sqrt{\beta_x}$ was found at the QF6 quadrupole, thus we added different sizes of apertures to QF6 and found the maximum acceptable aperture radii to be 0.003m (as shown in Fig. 1b), while the initial aperture size for QF6 is 0.016m (Such an aperture represents a very tight collimation, however the assumption on beam energy spread is very pessimistic, such that in practice looser collimation may be acceptable).

Vertical Halo Collimation

Several simulations of the vertical halo loss in ATF2 are also shown in Fig. 2. Halo losses on the vertical plane are mainly at QD10 and in the BDUMP bending magnet. Thus, in order to avoid the halo hitting on the BDUMP bending magnet, the initial aperture of 0.01m was gradually reduced. For 0.005m, no halo loss can be observed at the BDUMP bending magnet.

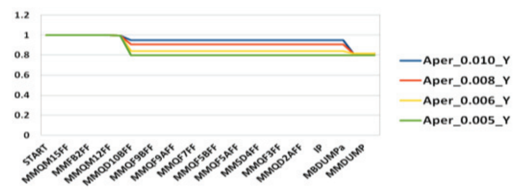

Figure 2: Simulation results for the ratio of halo loss in the vertical plane.

Beam Halo Measurement Using Wire Scanners

In order to get some updated information about the halo distribution for the current ATF2 beam line, in April 2013, several beam halo measurements were performed using the currently installed wire scanners: one in the extraction line and another one behind the IP (post-IP). These measurements are useful both for the understanding of backgrounds in the IPBSM and for the understanding of beam halo collimation requirements.

Preliminary analysis of measurements done with the post-IP wires is presented here. Both wires used are 50μm thick tungsten wires, located at 75cm downstream of the IP. A plastic scintillator detector together with a photomultiplier was used to detect the bremstrahlung photons generated when the halo hit the wire. Higher voltages were applied to the photomultiplier while measuring the region beyond ±3σ to obtain stronger signal. The results of horizontal and vertical beam halo measurements done at the post-IP wire scanners are shown in Fig. 3. The signal strengths were corrected for charge variations using an Integrating Current Transformer (ICT) and data taken with other voltages normalized to the beam core (from -3σ to +3σ). A Gaussian fit to the beam core was added to both plots beyond the core region to show the extent of the non-Gaussian beam tail. While the horizontal halo distribution is almost symmetric, the vertical halo distribution shows an asymmetry between the upside and the down side. We assume that the edge at around -20σ_y on the lower side reflects collimation by MREF3FF, a reference cavity with aperture radius of 0.008m, corresponding to 23σ_y.

Copyright © 2013 by JACoW — cc Creative Commons Attribution 3.0 (CC-BY-3.0)

ISBN 978-3-95450-122-9

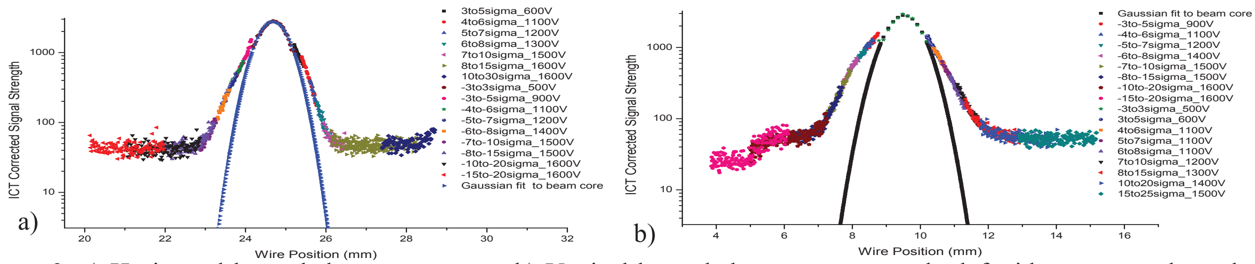

Figure 3: a) Horizontal beam halo measurement; b) Vertical beam halo measurement, the left side corresponds to the lower side of the beam.

DIAMOND DETECTOR R&D

Diamond, being the hardest material with a set of unique characteristics, has been studied and used for particle detection in high energy physics experiments for more than two decades [4]. With a band gap (5.5eV) 4 times larger than silicon, diamond presents a very low leakage current (few pA). Besides, diamond has a high breakdown field, high binding energy, large thermal conductivity and most importantly it has a very high mobility for both electrons and holes with an extremely fast pulse of less than 1ns.

The diamond samples are metalized with a thin layer (~ 100 nm) of either Al or Ti/Pt/Au. The electron beam passing through the diamond detector generates electron and hole pairs. When a bias voltage is applied between the two surfaces of the diamond detector, the electron-hole pairs will drift to the electrodes. The charge signal is then transported to the front-end readout electronics (an oscilloscope or more complicated ASIC) by a 50 ohm coaxial cables and the amplitude of the signal will be recorded.

Diamond Detector Test at PHIL

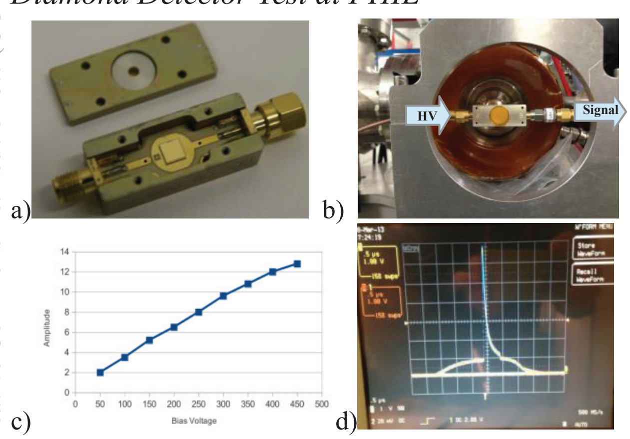

Figure 4: a) Diamond sample; b) Experimental setup at PHIL; c) Signal amplitude as a function of bias voltage applied on the diamond detector; d) Signal readout from diamond detector with a bias voltage of 200V.

Several tests of diamond detector have been performed at PHIL, a low energy (<10 MeV) electron beam accelerator at LAL, since the charge signal obtained from PHIL is very close to the charge created by the ATF2 beam. The diamond sample we used for the tests is a 500μm thick single crystalline diamond with a surface of 4.5×4.5mm^2, it is connected from one side to the input of high voltage and from the other side to an oscilloscope using 50m long coaxial cables (see Fig. 4a and 4b). The test results of signal amplitude as a function of bias voltage are shown in Fig. 4c. The signal amplitude changes linearly to the bias voltage. Figure 4d shows the signal readout from the beam generated by the laser on the photo cathode and a big pedestal tail, with a microsecond time scale, corresponding to the dark current.

CONCLUSIONS AND PROSPECTS

Beam halo collimation was studied in simulation using MAD-X. Betatron collimation may be needed for the vertical plane as well as energy collimation for the horizontal plane. Beam halo measurements were performed to check the distribution of beam halo at ATF2. Diamond detector R&D is still under progressing. The diamond detectors will be tested at PHIL in the vacuum chamber before installation at ATF2.

ACKNOWLEDGMENTS

The author would like to thank Pierre Barrillon, Selma Conforti, Hugues Monard and PHIL team for their help in the diamond test at PHIL.

REFERENCES

[1] P. Bambade et al., Phys. Rev. ST Accel. Beams 13, 042801 (2010).
[2] T. O. Raubenheimer, "The Core Emittance with Intrabeam Scattering in e$^+$/e$^-$ Rings" (Report No. SLAC-PUB-5790, 1992).
[3] T.Suehara et.al., "Design of a Nanometer Beam Size Monitor for ATF2", arXiv:0810.5467v1 (30 oct 2008).
[4] R. J. Tapper, "Diamond detectors in particle physics", Rep. Prog. Phys. 63 (2000), 1273.

Copyright © 2013 by JACoW — cc Creative Commons Attribution 3.0 (CC-BY-3.0)